

Outlook from SUSY07

John Ellis¹ ^a

Theory Division, Physics Department, CERN, CH 1211 Geneva 23, Switzerland

Abstract. Make-or-break time is near for the Higgs boson and supersymmetry. The LHC will soon put to the sword many theoretical ideas, and define the future for collider physics.

PACS. 1 1.15.Ex, 11.30.Pb, 12.10.-g, 12.60.Jv, 14.80.Bn

1 Introduction

I was in Karlsruhe in 1969 when the first astronauts landed on the Moon, realizing President Kennedy's commitment: 'this nation should commit itself to achieving the goal ... of landing a man on the Moon and returning him safely to the Earth'. Likewise, in 1994 the CERN Council committed the Organization to the goal of discovering the Higgs boson and supersymmetry (if they exist) at the LHC. Now, back in Karlsruhe, we supersymmetrists face the exhilarating prospect that our cherished ideas will soon be subjected to the ordeal of experimental test [1].

The organizers of this meeting explicitly exonerated me from giving a summary talk, asking me instead to present a personal outlook on the future (as offered by the LHC *et al*). Nevertheless, I have not quite taken them at their words, and base (at least some of) my talk on presentations made at SUSY07.

2 Hunting for the Higgs Boson

The LHC, with its centre-of-mass energy of 14 TeV and its nominal luminosity of $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ and the possibility of an upgrade to $10^{35} \text{ cm}^{-2}\text{s}^{-1}$ [2], offers the best prospects for discovering new physics beyond the Standard Model (SM). Since interesting cross sections such as those for supersymmetry and the Higgs boson are typically $\mathcal{O}(1)/(1 \text{ TeV})^2$, possibly with small prefactors $\mathcal{O}(\alpha^2)$, whereas the total cross section is $\mathcal{O}(1)/(100 \text{ MeV})^2$, looking for this interesting new physics will be like looking for a needle in 100,000 haystacks.

The Tevatron may have a chance of pipping the LHC in the race for the Higgs boson. Already, as seen in Fig. 1, the sensitivity of the combined CDF and D0 searches is within an order of magnitude of the cross section expected for the SM Higgs boson from the LEP lower limit up to $m_H \sim 190 \text{ GeV}$, the mass range allowed at the 95 % confidence level [3], and the sensitivity is within a factor 2 of the SM for $m_H \sim 160 \text{ GeV}$. Soon we may know whether the Higgs is either close to the LEP limit or in an 'unlikely' range.

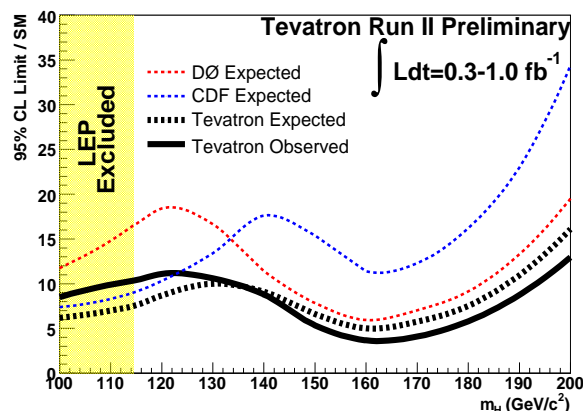


Fig. 1. Current combined upper limit from CDF and D0 on the production of a SM Higgs boson at the Tevatron [3].

The search for the Higgs boson at the LHC will require combining various different signatures [4], including $\gamma\gamma$, four-lepton final states, $\tau\tau$, $b\bar{b}$, WW and ZZ . As seen in Fig. 2, combining searches by ATLAS and CMS, 200 pb^{-1} should suffice to exclude a SM between about 140 and 500 GeV, 1 fb^{-1} should enable a SM Higgs boson to be discovered with $5\text{-}\sigma$ significance over a similar mass range, and 5 fb^{-1} should enable a discovery discover whatever its mass [5]. Eventually, if the Higgs mass $\sim 120 \text{ GeV}$, it should be possible at the LHC to measure SM Higgs couplings to $\tau\tau$, $b\bar{b}$, WW and ZZ with an accuracy $\sim 20\%$, and there are also prospects for measuring the Higgs spin via its decays into ZZ [6].

One of the biggest puzzles in Higgs physics is its contribution to vacuum energy. The naive Higgs potential $-\mu^2|H|^2 + \lambda|H|^4$ makes a negative contribution to the vacuum energy that is negative and some 60 orders of magnitude larger than the physical value of the dark energy. Some mysterious mechanism is needed to cancel this Higgs contribution to 60 decimal places. What are we missing? Are we barking up the wrong tree?

^a Email: John.Ellis@cern.ch

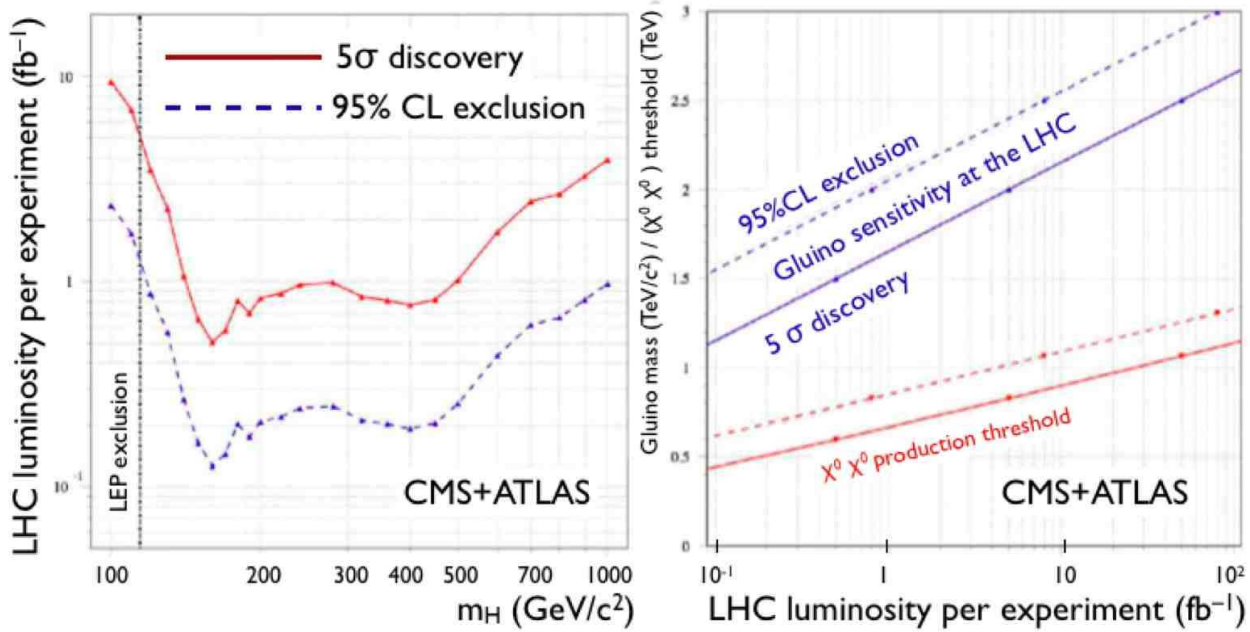


Fig. 2. The combined sensitivities of ATLAS and CMS to a Standard Model Higgs boson (left), and the gluino (right), as a function of the analyzed LHC luminosity. The right panel also shows the threshold for sparticle pair production at a LC for the corresponding gluino mass, calculated within the CMSSM [5].

3 Why Supersymmetry?

There are many motivations for supersymmetry, including its intrinsic beauty, its help in rendering the hierarchy of mass scales in fundamental physics more natural, its help in unifying the gauge couplings, its prediction that the Higgs boson should be relatively light: $m_H < 150$ GeV as suggested by precision electroweak data, and its offer of a natural cold dark matter candidate [7]. Moreover, it is (almost) an essential ingredient in string theory.

There have recently been several impressive pieces of direct observational evidence for collisionless cold dark matter, e.g., the ‘bullet cluster’ which has been shown by weak lensing to contain two lumps of dark matter that have passed through each other, while the associated gas clouds have collided, heated up and remained stuck in between [8]. On the other hand, there are problems for the cold dark matter paradigm provided, e.g., by dwarf spheroidal galaxies [9], the abundances of satellites of the Milky Way, and the apparent absence of cusps in galactic centres. Are we barking up the wrong tree again?

4 Constraints on Supersymmetry

There are important direct constraints on supersymmetry due to the absence of sparticles at LEP and the Tevatron, and also indirect constraints from, e.g., the LEP lower limit of 114 GeV on the Higgs mass, the success of SM calculations of $b \rightarrow s\gamma$, etc. One of the most important constraints is that imposed by the cold dark matter density, assuming it is largely composed of the lightest supersymmetric particle (LSP):

$0.094 < \Omega_{LSP} h^2 < 0.124$. There is still some debate about the interpretation of the BNL measurement of the anomalous magnetic moment of the muon ($g_\mu - 2$), which now disagrees by 3.4σ with a SM calculation based on low-energy e^+e^- data [10]. Recent e^+e^- data agree very well with earlier data, whereas preliminary new τ decay data apparently disagree with previous data.

Presumably the LSP has no strong or electromagnetic interactions, otherwise it would bind to conventional matter and be detectable as anomalous heavy nuclei. Possible weakly-interacting candidates include the sneutrino (though this seems to be excluded by LEP and direct searches), the lightest neutralino χ (a mixture of the spartners of the Z , H and γ), and the gravitino (which would be a nightmare for astrophysical detection, but a boon for colliders, as discussed later).

5 A Paradigm: the CMSSM with a neutralino LSP

For the rest of this talk, I focus on the minimal supersymmetric extension of the Standard Model (MSSM), including two Higgs doublets with coupling μ and a ratio of v.e.v.s denoted by $\tan \beta$. The MSSM has *a priori* unknown supersymmetry-breaking parameters, scalar masses m_0 , gaugino masses $m_{1/2}$, trilinear soft couplings A_0 , and a bilinear soft coupling B_0 . Universality at the input GUT scale is often assumed, the constrained MSSM (CMSSM) framework with a single m_0 , a single $m_{1/2}$, and a single A_0 . However, there is no necessity for the universality hypothesis in string theory. I emphasize that *the CMSSM is not the same*

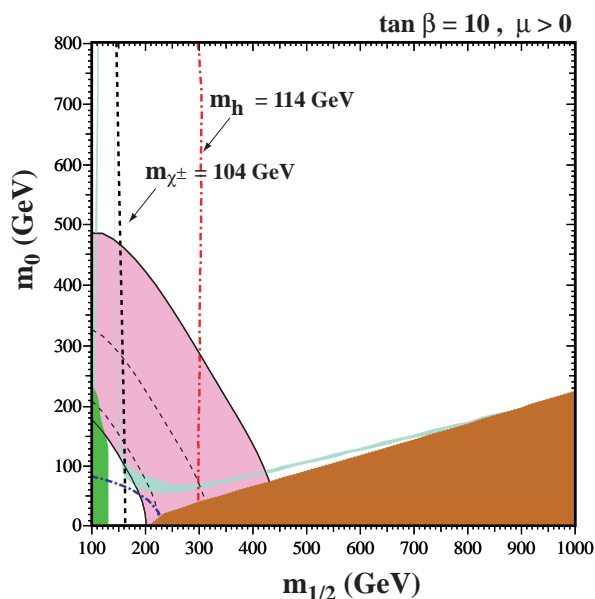


Fig. 3. The $(m_{1/2}, m_0)$ plane in the CMSSM for $\tan \beta = 10$, $\mu > 0$ and $A_0 = 0$ [11], incorporating the theoretical, experimental and cosmological constraints described in the text.

as *minimal supergravity* (mSUGRA), which imposes an relation on the gravitino mass: $m_{3/2} = m_0$, and the additional relation $B_0 = A_0 m_0$.

Fig. 3 is an example of the current constraints on the CMSSM [11], assuming that the LSP is the lightest neutralino χ , showing the region excluded because the LSP is the charged tau (shaded brown), excluded by $b \rightarrow s\gamma$ (shaded green), preferred by $g_\mu - 2$ (shaded pink) and by the cold dark matter density (shaded pale blue). The region allowed by these constraints extends to large $m_{1/2}$ (and there is another allowed region at large m_0), so sparticles may be quite heavy, as seen in Fig. 4 [12]. The red symbols are the full data sample, the blue symbols indicate models that could provide the astrophysical dark matter, the green symbols indicate models that are detectable at the LHC, and the yellow points are likely to be detectable directly in searches for dark matter scattering [13].

6 What Might be the Scale of Supersymmetry?

Is there any preference for any particular range of sparticle masses within this allowed band? Fig. 5 shows the χ^2 distributions for global fits to precision electroweak and B -decay data, assuming $\tan \beta = 10$ (left) and $\tan \beta = 50$ (right) [14]. We see that relatively low values of $m_{1/2} \sim 300, 600$ GeV are favoured, essentially by $g_\mu - 2$ (though there is also some support from m_W). Results from a more complete analysis of parameter space using a larger set of observables (with better graphics) are given in [15]. There may be good reason to hope that supersymmetry might be detectable at the LHC with 1 fb^{-1} of integrated luminosity.

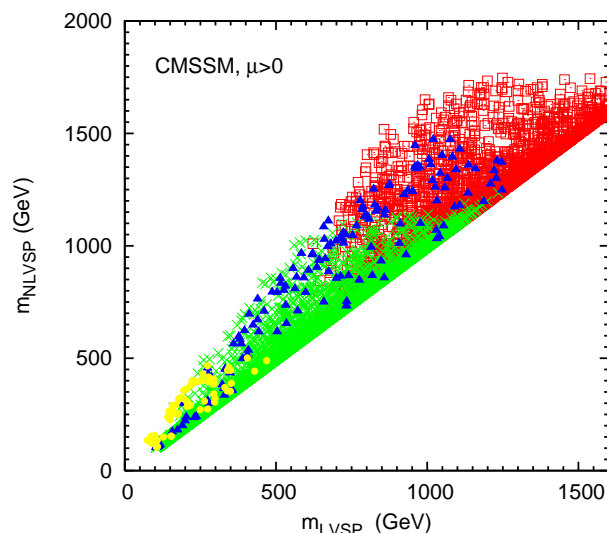


Fig. 4. The masses of the lightest and next-to-lightest visible supersymmetric particles in a sampling of CMSSM scenarios [12]. Also indicated are the scenarios providing a suitable amount of cold dark matter (blue), those detectable at the LHC (green) and those where the astrophysical dark matter might be detected directly (yellow).

7 Looking for Supersymmetry at the LHC

The classic supersymmetric signature is missing transverse energy carried away by dark matter particles. The Tevatron collider has already provided important limits on gluinos and squarks: $m_{\tilde{g}} > 290$ to 410 GeV and $m_{\tilde{q}} > 375$ GeV [3, 16] and has also provided important upper limits on trilepton final states as might arise from chargino and neutralino production [17]. Even with low initial luminosity, the LHC will immediately have sensitivity to gluino and squark masses far beyond the Tevatron limits. However, the missing-energy search will not be without backgrounds [18], it will be necessary to understand very well the ATLAS and CMS detectors.

A possible strategy for classic supersymmetry searches (and discovery?) at the LHC is [19]: (i) search for single lepton + missing-energy events, (ii) search for all combinations of dilepton + missing-energy events, (iii) search for trilepton + jet events, (iv) search for $b\bar{b}$ + lepton events, (v) search for zero-lepton + missing-energy events, etc. In addition, there will be searches for the photons characteristic of gauge-mediated scenarios and the metastable particles that might appear in scenarios with a gravitino LSP. Fig. 2 shows the sensitivity of the LHC to the gluino mass (both for five- σ discovery and 95 % exclusion) as a function of the integrated luminosity. For example, with 1 fb^{-1} the LHC might be able to discover a gluino weighing up to 1.7 TeV , or exclude a gluino weighing less than 2.1 TeV .

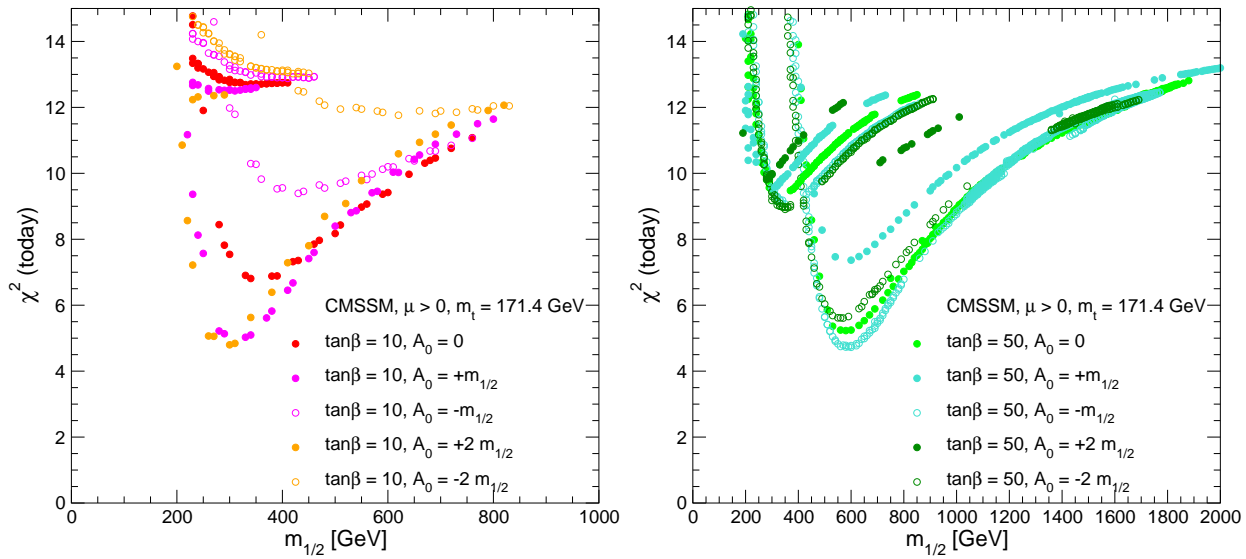


Fig. 5. The combined χ^2 function for electroweak precision observables and B -physics observables, evaluated in the CMSSM for $\tan\beta = 10$ (left) and $\tan\beta = 50$ (right) for various discrete values of A_0 . We use $m_t = 171.4 \pm 2.1$ GeV and $m_b(m_b) = 4.25 \pm 0.11$ GeV, and m_0 is chosen to yield the central value of the cold dark matter density indicated by WMAP and other observations for the central values of m_t and $m_b(m_b)$ [14].

8 The LHC Reach and Linear Colliders

The results of the LHC search for gluinos will carry important implications for future linear colliders [5], as illustrated in Fig. 2. Specifically, concentrating on the coannihilation region and models with unification of gaugino masses at the GUT scale, such as the CMSSM, discovery with 1 fb^{-1} would suggest that the $e^+e^- \rightarrow \chi\chi$ threshold lies below 650 GeV, whereas exclusion would exclude a threshold below 800 GeV. Well beyond the initial LHC luminosity, discovery of the gluino at the SLHC with a ‘year’ at a luminosity of $10^{35} \text{ cm}^{-2}\text{s}^{-1}$ would tell us that the $e^+e^- \rightarrow \chi\chi$ threshold lies below about 1.3 TeV. The LHC will tell us what energy a linear collider will need to study supersymmetry.

As is well known, the ILC would be able to make accurate measurements of the masses and couplings of any sparticles within its kinematic reach [20], and these measurements would have invaluable synergies with LHC measurements, for example by probing models of supersymmetry breaking by testing unification ideas [20]. However, supersymmetrists should be aware that not all scenarios with large cross sections at the LHC will necessarily be observable at the ILC [21]. A preliminary study of 242 such scenarios found that 158 or 65 % have no observable signal at the ILC with 500 GeV, and further investigation shows that the unobservable percentage actually rises to 75 %.

9 Supersymmetric Higgs Bosons

The LHC also has good prospects of discovering supersymmetric Higgs bosons, being able to cover entire generic $(m_A, \tan\beta)$ planes at least (but perhaps only) once. However, most points in the $(m_A, \tan\beta)$ planes corresponding to fixed values of $\mu, m_{1/2}$ and m_0 do

not have a cold dark matter density within the range favoured by WMAP and other astrophysical and cosmological measurements [22].

The situation changes in models with non-universal scalar masses. Upper limits on flavour-changing neutral interactions disfavour non-universal masses for sfermions in different generations but the same quantum numbers, e.g., d_R, s_R and b_R . Also, GUT models favour universal scalar masses for squarks and sleptons in the same multiplets, e.g., d_L, u_L, u_R and e_R (d_R and e_L) in the $\mathbf{10}(\mathbf{\bar{5}})$ of SU(5), or all the fermions of the same generation in SO(10). However, there is no known reason why the supersymmetry-breaking contributions to Higgs scalar masses should not be non-universal, a scenario known as the NUHM.

We have recently proposed and studied four WMAP-compatible $(m_A, \tan\beta)$ surfaces in the NUHM, using the non-universality parameters of the two Higgs multiplets to keep $\Omega_\chi h^2$ within the range favoured by WMAP et al [23, 22]. One of these WMAP-compatible surfaces have fixed $m_0 = 800$ GeV, fixed $\mu = 1000$ GeV, and varying $m_{1/2} \sim 9/8 m_A$, and another has fixed $m_{1/2} = 500$ GeV, fixed $m_0 = 1000$ GeV and varying $\mu \sim 250$ to 400 GeV. In each of these planes, we have made global fits to the electroweak precision and B observables, and analyze the models’ detectability at the Tevatron, LHC and ILC. For example, Fig. 6 displays the detectability of the $H/A \rightarrow \tau\tau$ signals at the Tevatron and LHC, and the accuracy with which the ILC could measure the $h \rightarrow b\bar{b}$ and WW branching ratios.

10 Gravitino Dark Matter?

As already mentioned, it is possible that the the LSP might be the gravitino [24], which would therefore pro-

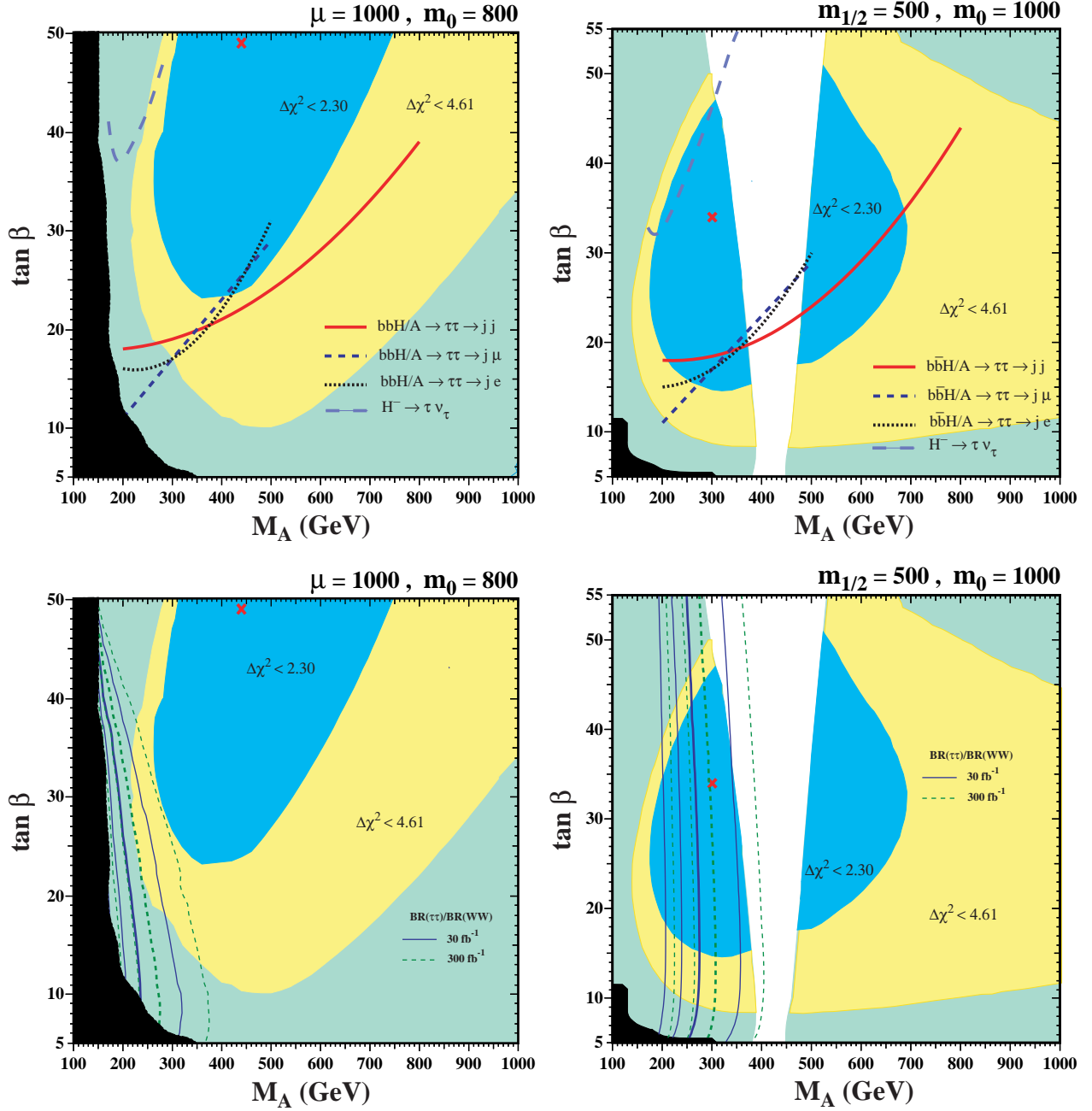


Fig. 6. WMAP-compatible $(M_A, \tan \beta)$ planes for two NUHM benchmark surfaces, displaying (top) the 5- σ discovery contours for $H/A \rightarrow \tau^+\tau^-$ at the LHC with 60 or 30 fb^{-1} (depending on the τ decay channels) and for $H^\pm \rightarrow \tau^\pm \nu$ detection in the CMS detector when $M_{H^\pm} > m_t$, and (bottom) the 1-, 2-, 3- and 5- σ contours (2- σ in bold) for SUSY-induced deviations from the SM value for the ratio $BR(h \rightarrow \tau^+\tau^-)/BR(h \rightarrow WW^*)$ at the LHC with 30 or 300 fb^{-1} [23].

vide the dark matter (GDM), and this is a generic possibility even in minimal supergravity (mSUGRA), as shown in Fig. 7. After taking into account the LEP and $b \rightarrow s\gamma$ constraints, there is a (pale blue) strip where the lightest neutralino is the LSP, a disallowed (brown) wedge where the LSP would be the lighter stau $\tilde{\tau}_1$ [24],

and another (yellow) wedge where the $\tilde{\tau}_1$ is the next-to-lightest sparticle (NLSP) and metastable, but its decays do not upset the cosmological light-element abundances.

It is a feature of any GDM scenario with gravity-mediated supersymmetry breaking that the NLSP has

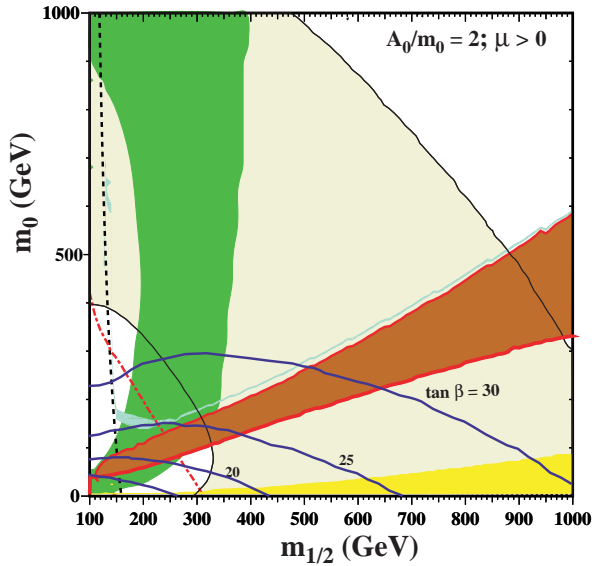


Fig. 7. Example of an mSUGRA $(m_{1/2}, m_0)$ plane with contours of $\tan \beta$ superposed, for $\mu > 0$ and $A_0/m_0 = 2.0$, $B_0 = A_0 - m_0$ [22]. The regions excluded by LEP are indicated, as are excluded by $b \rightarrow s\gamma$ decay (medium green shading), and the region favoured by $g_\mu - 2$ is light (beige) shaded. The region favoured by WMAP in the neutralino LSP case has light (blue) shading, and the regions with a stau NLSP that would be allowed by the cosmological BBN constraint (neglecting bound-state effects [25]) is light (yellow) shaded.

a very long lifetime due to gravitational decay, which might be measurable in hours, days, weeks, months or even years. Generic possibilities in models with non-universal scalar masses include the lightest neutralino $\tilde{\chi}$ as well as the lightest charged slepton (probably the $\tilde{\tau}_1$) [26], a sneutrino [27], or even the lighter stop quark \tilde{t}_1 [28].

A study of the ATLAS sensitivity to a metastable $\tilde{\tau}_1$ shows that events containing them would be selected with high efficiency by several separate triggers, via combinations of energetic muons, electrons or jets, without looking for a candidate $\tilde{\tau}_1$ track [29]. These could then be selected with high efficiency in an off-line analysis, and the $\tilde{\tau}_1$ mass determined by a combination of momentum and time-of-flight measurements, as shown in Fig. 8. The detected $\tilde{\tau}_1$'s may then be combined with jets and leptons in the final states to reconstruct invariant-mass peaks for heavier sparticles in such a GDM scenario [26].

The $\tilde{\tau}_1$'s produced at the LHC would typically be only moderately non-relativistic, with $\beta\gamma \sim 2$. The $\tilde{\tau}_1$'s with $\beta\gamma < 1$ would leave the central tracker after the next beam crossing, those with $\beta\gamma < 1/2$ would be stopped by ~ 10 m of matter, and those with $\beta\gamma < 1/4$ would likely be trapped inside the ATLAS calorimeter. We have wondered whether those with $1/4 < \beta\gamma < 1/2$ could be dug out of the LHC experimental cavern walls [30]. The idea would be to use the muon system to locate the impact point on the cavern wall with an uncertainty < 1 cm and the impact angle with an

accuracy $\sim 10^{-3}$ radians. One might then bore into the cavern wall and remove a core from the rock where the $\tilde{\tau}_1$ should have stopped, then wait for it to decay and observe its decay products. However, one must beware of the radioactivity induced by LHC collisions. Once a month it is planned to make a technical stop of the LHC for two days, during which one could work in the cavern. This would be useful if the $\tilde{\tau}_1$ lifetime is more than about 10^6 s, but not if it is much shorter.

There is, however, an additional cosmological effect that needs to be taken into account. If the NLSP is charged (like the $\tilde{\tau}_1$), it may form bound states in the early Universe, which would have additional effects on the light-element abundances [25]. Under certain circumstances, these might even *improve* the agreement of theoretical calculations with the observed abundances of ${}^6,{}^7\text{Li}$ [31]. However, this is possible only in very restricted regions of the GDM parameter space, in which the NLSP is relatively heavy (at least in the first examples studied).

11 Complexification of the CMSSM

Assuming universal soft supersymmetry-breaking parameters, as in the CMSSM, there are two new CP-violating phases beyond those in the SM, namely $\text{Arg}(m_{1/2}\mu)$ and $\text{Arg}(A_0\mu)$ [32]. At the loop level, these induce mixing between the CP-even and -odd neutral Higgs bosons of the CMSSM, so that $(h, H, A) \rightarrow (H_1, H_2, H_3)$ with indefinite CP. As seen in Fig. 9, the new CP-violating parameters affect the couplings of the MSSM Higgs bosons as well as their masses. The phases could in principle allow the lightest CMSSM Higgs boson to be lighter than in the usual limit in the MSSM with real parameters, but they are subject to important constraints imposed by upper limits on electric dipole moments. There are prospects for probing these phases at the LHC, in both the Higgs and sparticle sectors.

12 Supersymmetric Flavour Physics

The flavour and CP structure of any new physics at the TeV scale is tightly constrained by the continuing agreement of data from the B factories and the Tevatron with the predictions of the SM, e.g., their measurements of $b \rightarrow s\gamma$ and $B_u \rightarrow \tau\nu$, and their upper limits on $B_s \rightarrow \mu\nu\mu^+\mu^-$. Improvements in these measurements and limits are places to look for supersymmetric flavour physics, and other opportunities may be provided by K physics [34], for example in the search for violations of flavour universality in $K \rightarrow e\nu$ and $K \rightarrow \mu\nu$ decays [35], or in $K \rightarrow \pi\nu\nu$ decays. Charged leptons may also play roles in unravelling the supersymmetric flavour puzzle. For example, in supersymmetric extensions of the see-saw model for neutrino masses, the lepton-flavour-violating processes $\mu \rightarrow e\gamma$ and $\tau \rightarrow \mu(e)\gamma$ may occur at observable rates [36, 37, 38], as illustrated in Fig. 10.

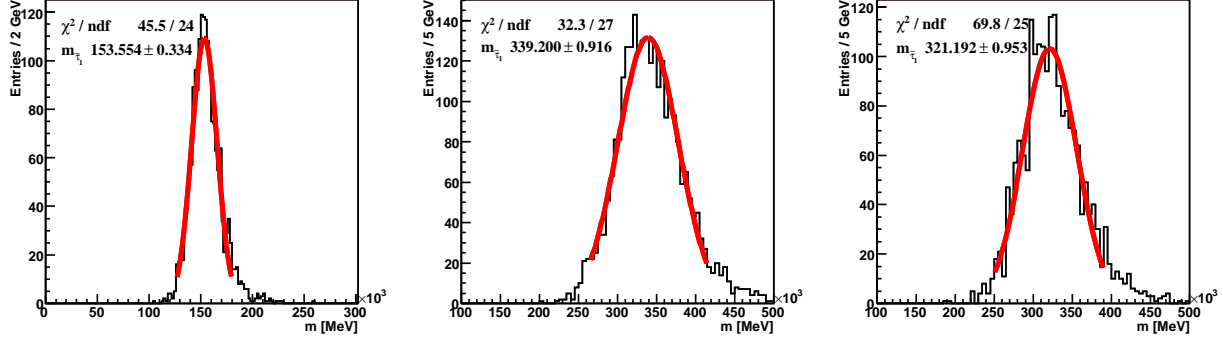


Fig. 8. The mass of a metastable stau could be measured quite accurately at the LHC [29], as exemplified in three benchmark scenarios [30].

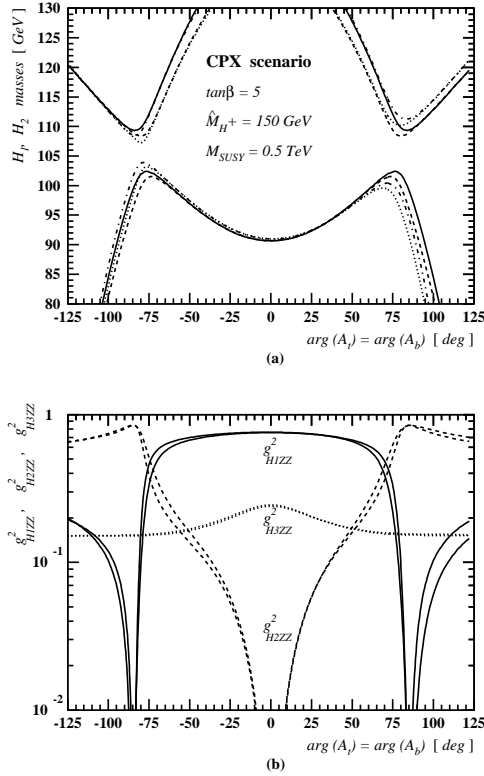


Fig. 9. Numerical estimates of (a) the $H_{1,2}$ -effective-potential and pole masses and (b) g_{HZZ}^2 as functions of $\text{Arg}(A_0\mu)$, in a CP-violating scenario with $M_{\text{SUSY}} = 0.5$ TeV, $\text{Arg}(m_{1/2}\mu) = 0$ and 90° . In plot (a), the effective-potential mass M_{H_1} (M_{H_2}) is indicated by a solid (dash-dotted) line for $\text{Arg}(m_{1/2}\mu) = 0$ (90°), and its pole mass \hat{M}_{H_1} (\hat{M}_{H_2}) by a dashed (dotted) line for $\text{Arg}(m_{1/2}\mu) = 0$ (90°) [33].

13 Suggestions from String Theory?

The full enormity of the ambiguity in the string vacuum has sunk in only recently, with numbers $\mathcal{O}(10^{500})$ being bandied about [39]. This ambiguity arises because there are certainly millions and perhaps billions

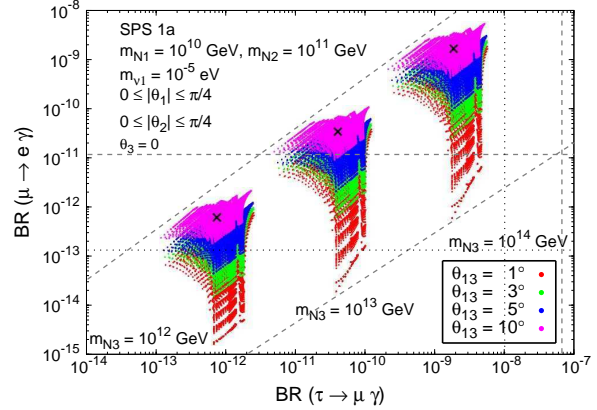


Fig. 10. Correlation between $BR(\mu \rightarrow e\gamma)$ and $BR(\tau \rightarrow \mu\gamma)$ for different m_{N_3} , displaying the impact of θ_{13} with a scan over θ_i [37]. The horizontal and vertical dashed (dotted) lines denote the experimental bounds (future sensitivities).

of consistent compactifications of strings on manifolds in extra dimensions, and each of these has dozens or hundreds of topological cycles through which there may be topological fluxes taking any of dozens of values. Somewhere in this landscape of an enormous number of string vacua, it is suggested there may be one with a vacuum energy in the range indicated by the cosmology dark energy. The question then arises how the Universe chooses which of these vacua. One may also wonder whether, since nature apparently has the opportunity to choose a small vacuum energy, perhaps it also chooses a small value of m_W , in which case there might be no need for supersymmetry to render the choice natural.

Indeed, ideas for models without supersymmetry (or even a Higgs boson) were also discussed here [40], and a unified discussion of alternatives has been presented. As illustrated in Fig. 11, there is a continuum of alternatives to the supersymmetric paradigm, ranging from little Higgs models to holographic pseudo-Nambu-Goldstone-boson Higgs models to Randall-Sundrum scenarios to Higgsless models to technicolour models and back again. The good news is that many

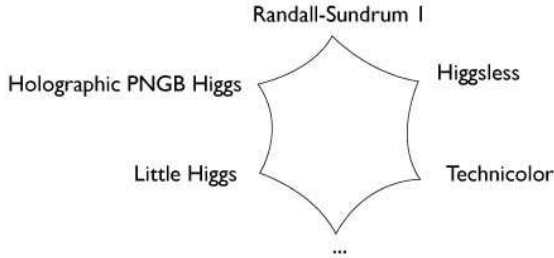


Fig. 11. An illustration of the space of possible alternatives to supersymmetry at low energies [40].

(most? all?) of these scenarios can be tested at the LHC.

An different question revived by the string landscape within the supersymmetric paradigm is whether we live in a metastable vacuum [41], a possibility discussed a long time ago as an exotic possibility in the framework of global supersymmetry [42]. If there are indeed myriads of consistent string vacua, it seems difficult to see why we should be living in the one that is energetically preferred.

The mainstream hope would be that string theory would add value to the MSSM by predicting the exact spectrum and grand unification, incorporating gauge and/or Yukawa unification and the see-saw mechanism and providing an explicit mechanism for breaking supersymmetry, e.g., via gaugino condensation [43]. One interesting variant of the conventional CMSSM scenario is the possibility of ‘mirage unification’, in which gaugino masses unify below the GUT scale as a result of mixed modulus and anomaly contributions to gaugino masses [44]:

$$M_a = M_s(\rho + b_a g_a^2). \quad (1)$$

Lowering the unification scale could have a dramatic effect on the phenomenology discussed previously in the CMSSM context. As seen in the top panel of Fig. 12, the expected values of the sparticle masses change as the effective universality scale M_{in} is reduced and, as a consequence, the regions of parameter space favoured by cosmology may change significantly [45, 22], as seen in the lower panel of Fig. 12. The LHC may soon tell us, in more ways than one, whether supersymmetry is a mirage!

14 Conclusions

LEP and the Tevatron have already advanced in the quests for supersymmetry and the Higgs boson, and these searches being continued by the Tevatron. In parallel, searches for supersymmetry have been underway in low-energy precision physics and in direct and indirect searches for dark matter, and will continue during the LHC era. However, the LHC will be the first accelerator to reveal to us directly what new physics exists at the electroweak scale. Without results from the LHC, starting around 2010, we will not know what major subsequent new accelerator investments would be

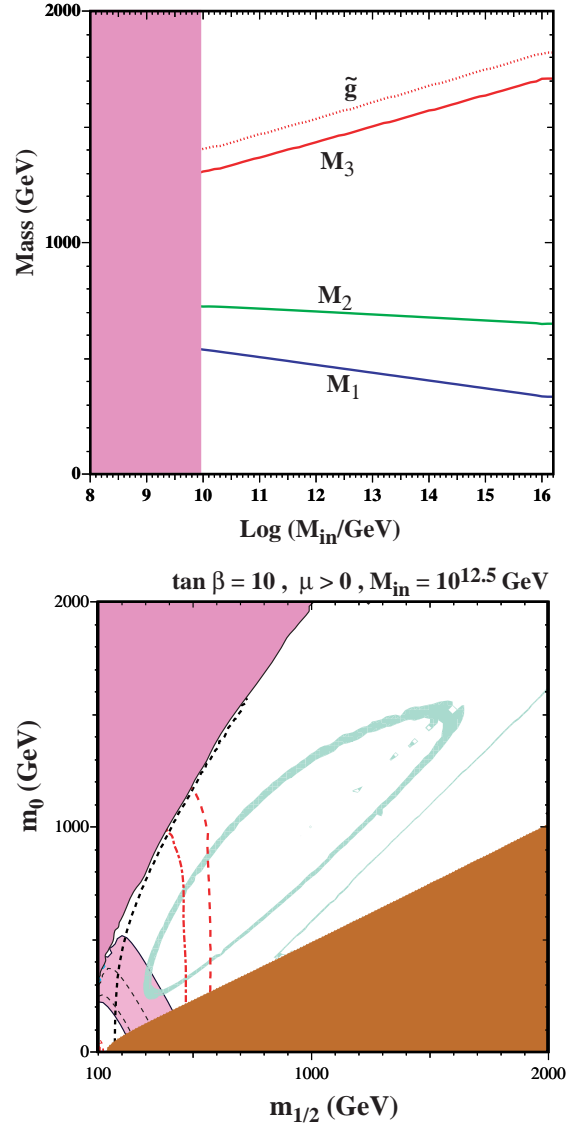


Fig. 12. Evolution (top) of the gaugino mass parameters and the physical gluino mass as the effective ‘mirage’ unification scale M_{in} is reduced, and (below) an example of an $(m_{1/2}, m_0)$ plane with $\tan \beta = 10$ and $A_0 = 0$ and $M_{in} = 10^{12.5}$ GeV, using the same notation as in Fig. 3. The region favoured by WMAP is very different from that in the CMSSM with GUT-scale universality.

optimal. One possibility, that would optimize the scientific return from immense investment that the community has made in the LHC, would be to improve its luminosity, perhaps by an order of magnitude. This would surely be interesting in many supersymmetric and other scenarios for physics beyond the SM. On a longer time-scale, there is general agreement that a linear e^+e^- collider would be an ideal tool for studying in detail any new physics revealed by the LHC, *provided it lies within the accessible energy range*. Only time and the LHC will tell us whether the ILC will have sufficient energy, or whether physics will demand higher energy, as could be provided by CLIC.

References

1. F. Wilczek, arXiv:0708.4236 [hep-ph].
2. L. Evans, talk at this conference: see also <http://lhc.web.cern.ch/lhc/>.
3. A. Duperrin, for the CDF and D0 Collaborations, arXiv:0710.4265 [hep-ex].
4. K. Jakobs, talk at this conference, see also:
5. A. Blondel, L. Camilleri, A. Ceccucci, J. Ellis, M. Lindroos, M. Mangano and G. Rolandi, *Physics opportunities with future proton accelerators at CERN*, arXiv:hep-ph/0609102.
6. C. Ruwiedel [ATLAS Collaboration], arXiv:0710.1954 [hep-ph].
7. J. R. Ellis, J. S. Hagelin, D. V. Nanopoulos, K. A. Olive and M. Srednicki, Nucl. Phys. B **238** (1984) 453.
8. M. Bradac *et al.*, Astrophys. J. **652** (2006) 937 [arXiv:astro-ph/0608408].
9. G. Gilmore, M. I. Wilkinson, R. F. G. Wyse, J. T. Kleyna, A. Koch, N. W. Evans and E. K. Grebel, arXiv:astro-ph/0703308.
10. A. Czarnecki, talk at this meeting.
11. J. R. Ellis, K. A. Olive, Y. Santoso and V. C. Spanos, Phys. Lett. B **565** (2003) 176 [arXiv:hep-ph/0303043].
12. J. R. Ellis, K. A. Olive, Y. Santoso and V. C. Spanos, Phys. Lett. B **603** (2004) 51 [arXiv:hep-ph/0408118].
13. D. Hooper, arXiv:0710.2062 [hep-ph].
14. J. R. Ellis, S. Heinemeyer, K. A. Olive, A. M. Weber and G. Weiglein, JHEP **0708** (2007) 083 [arXiv:0706.0652 [hep-ph]].
15. O. Buchmueller *et al.*, arXiv:0707.3447 [hep-ph].
16. M. Shamim, for the D0 Collaboration, arXiv:0710.2897 [hep-ex].
17. E. Lytken, for the CDF collaboration, arXiv:0710.2670 [hep-ex]; O. Mundal, for the D0 Collaboration, arXiv:0710.4098 [hep-ex].
18. M. L. Mangano, talk at this meeting; see also: J. Alwall *et al.*, arXiv:0706.2569 [hep-ph].
19. M. Spiropoulou, talk at this meeting; see also: M. Tytgat, arXiv:0710.1013 [hep-ex].
20. S. Y. Choi, talk at this meeting; see also: G. Weiglein *et al.* [LHC/LC Study Group], Phys. Rept. **426** (2006) 47 [arXiv:hep-ph/0410364].
21. B. Lillie, talk at this meeting.
22. K. A. Olive, arXiv:0709.3303 [hep-ph].
23. J. Ellis, T. Hahn, S. Heinemeyer, K. A. Olive and G. Weiglein, arXiv:0709.0098 [hep-ph].
24. F. Steffen, talk at this meeting; see also: H. U. Martyn, arXiv:0709.1030 [hep-ph]; S. Bressler, for the ATLAS Collaboration, arXiv:0710.2111 [hep-ex]; A. V. Gladyshev, D. I. Kazakov and M. G. Paucar, arXiv:0710.2322 [hep-ph].
25. M. Pospelov, Phys. Rev. Lett. **98** (2007) 231301 [arXiv:hep-ph/0605215]; see also: J. Pradler and F. D. Steffen, arXiv:0710.4548 [hep-ph] and arXiv:0710.2213 [hep-ph].
26. J. R. Ellis, A. R. Raklev and O. K. Oye, JHEP **0610** (2006) 061 [arXiv:hep-ph/0607261].
27. L. Covi and S. Kraml, JHEP **0708** (2007) 015 [arXiv:hep-ph/0703130].
28. J. L. Diaz-Cruz, J. R. Ellis, K. A. Olive and Y. Santoso, JHEP **0705** (2007) 003 [arXiv:hep-ph/0701229]; see also: Y. Santoso, arXiv:0709.3952 [hep-ph].
29. J. R. Ellis, A. R. Raklev and O. K. Oye, ATLAS Note ATL-PHYS-PUB-2007-016 (2007).
30. A. De Roeck, J. R. Ellis, F. Gianotti, F. Moortgat, K. A. Olive and L. Pape, Eur. Phys. J. C **49** (2007) 1041 [arXiv:hep-ph/0508198].
31. R. H. Cyburt, J. R. Ellis, B. D. Fields, K. A. Olive and V. C. Spanos, JCAP **0611** (2006) 014 [arXiv:astro-ph/0608562].
32. S. Kraml, talk at this meeting; see also: E. Accomando *et al.*, arXiv:hep-ph/0608079; S. Scopel and J. Sik Lee, arXiv:0710.2578 [hep-ph].
33. M. S. Carena, J. R. Ellis, A. Pilaftsis and C. E. M. Wagner, Nucl. Phys. B **625** (2002) 345 [arXiv:hep-ph/0111245].
34. C. Smith, arXiv:0710.2883 [hep-ph].
35. A. Masiero, P. Paradisi and R. Petronzio, Phys. Rev. D **74** (2006) 011701 [arXiv:hep-ph/0511289].
36. A. Masiero, talk at this meeting.
37. E. Arganda and M. J. Herrero, arXiv:0710.4091 [hep-ph].
38. F. Deppisch, arXiv:0710.2525 [hep-ph].
39. A. Linde, talk at this meeting; see also: F. Gmeiner, arXiv:0710.2468 [hep-th].
40. H. C. Cheng, arXiv:0710.3407 [hep-ph]; see also: J. Reuter, arXiv:0709.3816 [hep-ph].
41. K. Intriligator, N. Seiberg and D. Shih, JHEP **0604** (2006) 021 [arXiv:hep-th/0602239].
42. J. R. Ellis, C. H. Llewellyn Smith and G. G. Ross, Phys. Lett. B **114** (1982) 227.
43. H. P. Nilles, talk at this meeting.
44. M. Endo, M. Yamaguchi and K. Yoshioka, Phys. Rev. D **72** (2005) 015004 [arXiv:hep-ph/0504036]; JHEP **0509** (2005) 039 [arXiv:hep-ph/0504037].
45. P. Sandick, arXiv:0710.1843 [hep-ph]; see also: J. R. Ellis, K. A. Olive and P. Sandick, Phys. Lett. B **642** (2006) 389 [arXiv:hep-ph/0607002]; J. R. Ellis, K. A. Olive and P. Sandick, JHEP **0706** (2007) 079 [arXiv:0704.3446 [hep-ph]].